Smoke and Heat Vents:
A review of the technology and the way forward to the next generation

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Introduction

The hazards and damage from fire are dominated by the effects of smoke and heat. In terms of egress of building occupants, loss of visibility by smoke obscuration is the primary hazard which impedes safe escape from a building fire. In terms of fire deaths, the smoke inhalation is the primary hazard when individuals are not initially intimate with the fire. In terms of property damage, the area of damage due to direct flame damage is most often a small fraction of the area damaged by smoke and heat. All this speaks to the need to control the production of smoke and heat and to manage the movement of smoke and heat within the building.

The primary means of controlling the production of smoke and heat is to suppress the fire by automatic means or by manual firefighting. Even when automatic suppression systems are employed, manual firefighting by the fire department is an integral part of the process of fire suppression. An additional means of controlling the fire is through the use of compartmentation. This method is generally valuable in limiting the spread of fire, smoke, and heat. However, in many single story buildings used for manufacturing and storage, large open areas are essential for effective building operations. In these and other single story buildings, smoke and heat venting provides a means of limiting the spread of smoke and heat without limiting the open areas needed for operations. Thus, smoke and heat venting plays an integral role in the control of hazards due to fires in large open area single story buildings.

The specific benefits of smoke and heat venting include:

1. Facilitate safe egress of building occupants by restricting spread of smoke and hot gases into escape routes

2. Facilitate firefighting operations by enabling firefighters to enter the building and to see the seat of the fire without the delay and hazards of manual roof venting

3. Limit damage to the building and contents due to smoke and heat by removing smoke and heat from the building

Each of these is achieved by preventing smoke logging of the building down to occupied levels of the building where people require adequate visibility to escape and where adequate visibility facilitates the firefighters finding and extinguishing the fire. Limiting smoke damage to the building and contents is achieved by removing the smoke. This limits the exposure of the building interior and contents to smoke deposition.

Historical Development of the Technology

Recognition of the value of smoke and heat venting dates back to the beginning of the 20th century, when requirements for such venting were included for theater stages. However, serious consideration of their use in large open area buildings arose in the 1950's after the disastrous fire at the Lavonia GM plant in 1955. This fire gave rise to significant research at Factory Mutual and the UK Fire Research Station, as well as in Japan and the USSR. By the early 1960's a substantive knowledge base on the physics of smoke and heat venting was in place. In fact mathematical models were developed during this time frame that included the effect of fire size on the required vent area. Smoke and heat venting was the first successful application of zone fire modeling to fire protection engineering design.

In the same time frame (1960's), NFPA developed the Guide for Smoke and Heat Venting, NFPA 204. While the theory of vent design was emerging at this time, the guide recognized but did not embrace a mathematical approach to vent design. However, it did recognize the importance of heat release rate, providing for vent spacing dependent upon the fuel load and heat release rate for the occupancy. This general approach to smoke and heat vent design was subsequently introduced into the model building codes and remains in the IBC. Smoke and heat vents have been listed/approved by UL and FM since the early 1970's and are currently evaluated by the ICC Evaluation Service, Inc.

In the 1970's controversy arose concerning the interaction of smoke and heat venting with sprinklers. This controversy seemed to have crippled the development of smoke and heat venting design methods. In 1982, NFPA 204 set aside the issues with the use of smoke and heat venting in sprinklered buildings and embraced the mathematical modeling approaches that had been developing since the late 1950's for nonsprinklered buildings. The modeling equations included in NFPA 204 through the efforts of Gunnar Heskestad of Factory Mutual Research Corporation are essentially an algebraic modeling approach with its roots in the early 1960's. This timing corresponded to a period when the concepts of fire growth were being further developed, including the now commonplace use of t-squared design fires.

In 1998 NFPA 204 further embraced modeling approaches to smoke and heat venting design by incorporating the zone fire model LAVENT and the plume/ceiling jet model DETACT into the design methodology. LAVENT was developed by Len Cooper specifically for smoke and heat venting applications. DETACT was developed in the 1980's by Evans and Stroup for the prediction of detector activation, based upon earlier work that had been used to develop design tables in NFPA 72E in the early 1980's.

In 2002, NFPA 204 was revised from a guide to a standard. This was undertaken so that it could become a reference standard for model building codes. This was the first of the three smoke management guides to be revised as a standard. At this time NFPA 92A

(2006), 92B (2005), and 204 (2002) are all in the form of standards. NFPA 92B has been adopted as a reference standard in the IBC. At this time neither NFPA 92A or 204 have been put forward for consideration by the IBC. In the case of NFPA 92A, the standard was not yet in place at the time of the last cycle of the IBC and as such 92A has not yet been put forward for IBC consideration. In the case of NFPA 204, the standard has not been put forward for consideration by IBC pending the development of a design methodology for sprinklered facilities.

Role of Smoke and Heat Venting in the Codes

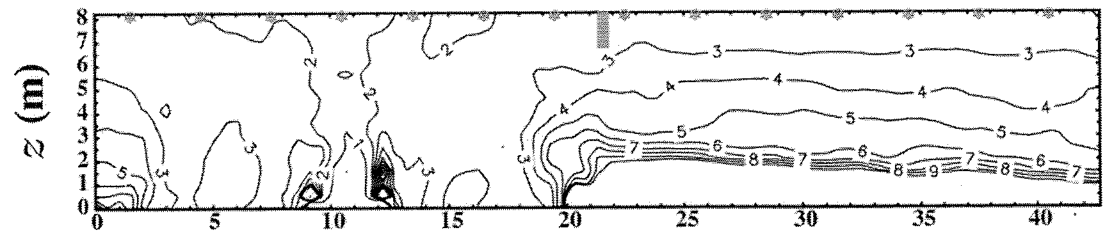
Smoke and heat venting is an active form of fire protection required in single story Groups F-1 and S-1 occupancies greater than 50,000 square feet in undivided area. Activation of the smoke and heat vents by a fire detection device causes smoke and heat to be removed from the building. Automatic sprinklers are required in these occupancies for areas greater than 12,000 square feet. As such, smoke and heat venting, in conjunction with automatic sprinklers, serves as an active fire protection system alternative to compartmentation of factory and storage facilities. Active smoke and heat venting provides a means of controlling the spread of smoke and heat in lieu of passive partitions in order to accommodate large open floor areas which are important to efficient and effective operations in many factory and/or storage facilities.

Smoke and Heat Venting with Sprinklers

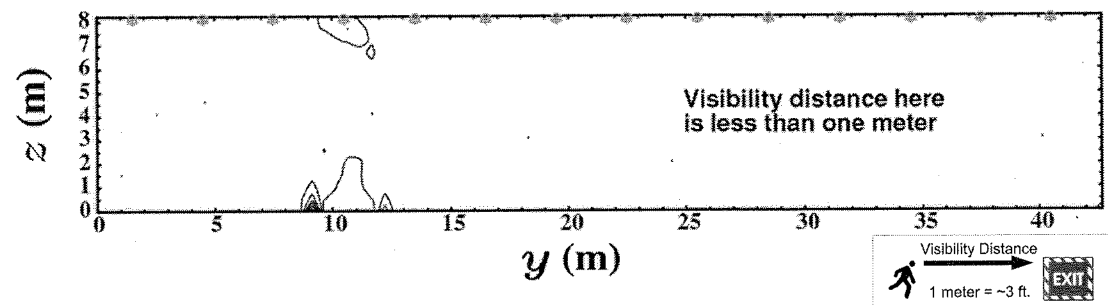
As indicated in a prior section, there has been a long standing concern with the use of smoke and heat venting in sprinklered facilities. In 2001 Beyler and Cooper published a review of the relevant research conducted to address this issue. A total of thirteen experimental studies from 1955 to 1998 were identified and reviewed. A total of 34 position papers were identified on the subject. The review paper used the 34 position papers to identify all the positive and negative claims proffered over the years with respect to the use of smoke and heat venting in sprinklered facilities. The thirteen experimental programs were used to evaluate all of the identified claims.

The findings of the review were that smoke and heat venting does not negatively impact sprinkler performance. The review also found that smoke and heat venting did limit the spread of smoke and heat so as to benefit building occupants and firefighters and reduce smoke and heat damage. At the same time, the review identified that the design methods currently employed may limit the number of vents operating during successful sprinkler operation to one or, possibly none, in very successful sprinkler operations. The review found that additional work is needed to develop more effective design methods.

In a Letter to the Editor in the following year, Gunnar Heskestad concurred that additional research is required to develop design methods for smoke and heat venting in sprinklered facilities. He indicated concern that adequate attention be paid to assuring that vents and draft curtains do not interfere with the operation of sprinklers which deliver water to the fire.



(a) Domain with smoke curtains and smoke vents.



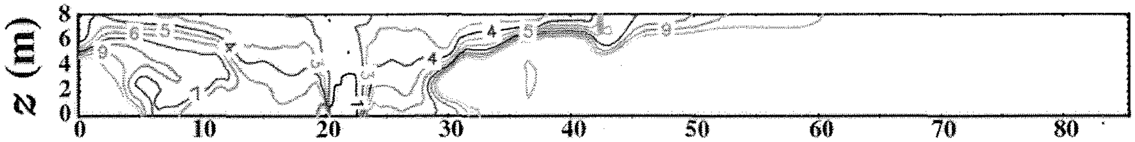
(b) Domain without smoke curtains and smoke vents.

Figure 1. Visibility (m) at x = 10.7 m and t = 600 s for two simulations where four smoke vents were and were not opened simultaneously. This plane cuts through the center of the fire.

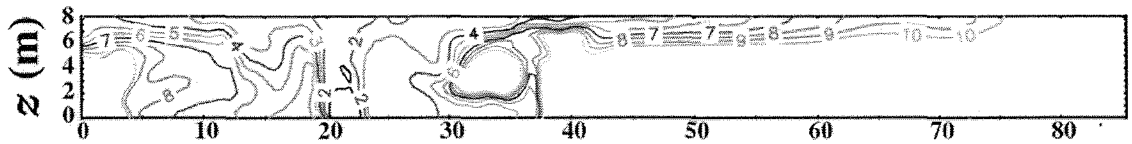
Next Generation Design Method

Based upon the results of the literature review, work began on developing a design method for smoke and heat venting for sprinklered facilities. While the effect of sprinkler sprays upon vent performance was not ignored entirely by the research community, the controversy over sprinklers and vents seemed to have effectively suppressed substantive activity in research into design methods.

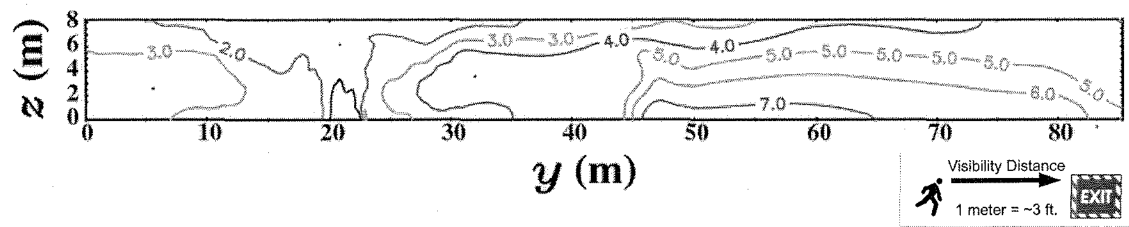
With the emergence of highly sophisticated computational fluid dynamics based fire models, the initial approaches to design method development had sought to use these methods. HAI performed modeling studies using LES 3D (now FDS 4) for a 140'×140'×27' sprinklered facility, divided into four draft curtained areas, with four 8'×4' vents per curtained area. The fire modeled was a t-squared fire reaching 10 MW in 75 s, and was controlled at that rate for 600 seconds. The number of vents simulated to open was parametrically varied from zero to four. For all cases modeled visibility was lost within the sprinkler discharge area, but outside the area of sprinkler operation, increasing the number of vents operating improved visibility. Figure 1 shows the visibility distance over a section of the modeled domain at 600 seconds after fire initiation for the four vent case and the zero vent case. The fire is centered within the left curtained area (at ~10 m) and about 20 sprinklers operated in both cases. The conditions outside the sprinkler discharge area are typified by the right half of the section. In this case, the venting clearly changed the conditions for occupants and firefighters from near blackout conditions to navigable smoke conditions.



(a) Domain with smoke curtains, four smoke vents opened simultaneously.



(b) Domain without smoke curtains, four smoke vents opened simultaneously.



(c) Domain without smoke curtains or smoke vents.

Figure 2. Visibility (m) at x = 21.3 m and t = 600 s for three simulations with the indicated smoke vent and smoke curtain conditions. Since the fire is in this plane, these figures show the highest obscuration achieved in each simulation.

The results and the trend in the results were consistent with the general view developed from the literature review. This and similar model results indicated that in many fires, too few vents operate. This was found to be exacerbated by the use of high temperature links for vents.

The need for more vents to operate to be effective and the desire to not operate vents before sprinklers operate led to the concept of ganged vent operation based upon the activation of the sprinkler system water flow alarm device. In this way all the vents in a curtained area could be opened soon after the first sprinklers operated. To explore this scenario, modeling was carried out in a larger 280'×280'×27' building divided into four curtained areas. Each curtained area was approximately 20,000 square feet which could reasonably be protected by a single sprinkler system. Due to the four times larger curtained area, the number of vents was increased from 4 to 16.

The fire modeled was a t-squared fire reaching 10 MW in 75 s, and was controlled at that rate for 600 seconds, just as before. Calculations were done without vents or draft curtains, with vents and no draft curtains, and with both vents and draft curtains. Vents were opened at least 30 seconds after the first sprinkler operated. At this time all the sprinklers which could contribute to fire suppression had already operated. In the unvented case, smoke was distributed throughout the facility, leading to widespread loss of visibility. The vent cases limited the spread of smoke and visibility was maintained outside the area of sprinkler operation. While performance was better with draft curtains, the results without draft curtains were quite promising. The results at 600 seconds for these three cases are shown in Figure 2. The results are quite promising that ganged operation of vents based upon water flow is a viable smoke management strategy in sprinklered buildings.

The above calculations were of an exploratory nature. A more complete series of parametric modeling studies are needed to support the development of a smoke and heat venting design method. While great strides have been made in fire modeling in recent years, it is not yet possible to predict fire suppression by sprinklers. Fortunately, this is not required to solve the design problem. It is necessary, however, to examine smoke and heat venting over a range of sprinkler performances from fires suppressed by a small number of sprinklers to those which result in sprinkler operation over the entire design area. Enough is known from the available testing to simulate the nature of the heat release rate curves associated with the range of possible performance levels so that smoke and heat venting in fires controlled by as few as four sprinklers and up to the number of sprinklers that constitute the full design area can be simulated.

Indeed, it has been recognized that full scale sprinkler tests are not very reproducible and this makes studying the venting problem with sprinklers very difficult. As a result, even the testing program earlier envisioned relied upon programmed spray burners simulating fire development in rack fires with only one or two full scale fire tests to be conducted at the end of the program to validate performance with actual commodities.

Because of the difficulties with performing a full scale fire test series and because of the advancement of fire modeling capabilities, it is now considered feasible to develop the design methodology using fire modeling methods. There is presently a modeling study underway to provide the needed parametric studies to support design method development for sprinklered buildings. Initial modeling scenarios will parametrically evaluate fire growth history, the area of ganged operation, and fire location relative to the ganged operating area. The modeling proposes to use 20 foot double rack storage of Group A plastics as the storage arrangement.

The modeling work will be brought to the NFPA Technical Committee on Smoke Management Systems as a starting point for the development of a design method for smoke and heat venting in sprinklered facilities to be incorporated into NFPA 204. It is envisioned that when the work of the Technical Committee is complete, NFPA 204 will be proposed to be used as an IBC reference standard for smoke and heat venting design in much the same way that NFPA 92B has been adopted for atrium smoke management design. This follows a technology development path that has been successfully used in the past.